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NEUTRON BEAM SHIELDING AT ISIS

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INTRODUCTION

This paper presents some of the details and rationale behind the neutron beam shielding concepts employed at ISIS. These concepts have now been evaluated at 20 μA operation (1/10 of final design goal) and we are happy to report that no significant ($\geq$10 μS/hr) radiation levels have been experienced in the experimental hall.

BULK SHIELD

The bulk shield has a radius of 5.9 m and is of a conventional design with an iron core and concrete outer shell. The inner void vessel, which contains the target-moderator assembly, has a radius of 1.6 m. The ratio of iron to concrete is 3:1, and the dimensions are dictated by the need to attenuate the hard component (> 100 MeV) of the spectrum, so there is some enhancement of the shield in the forward direction. Figure 1a illustrates the general layout.

Eighteen inserts are provided through the bulk shield, see Figure 1b. Within each insert, neutron beam collimation systems may be constructed which view any moderator (upper, lower, front, rear). This flexibility will allow the beam configuration to be changed, if required by the scientific programme, without disturbing the general shield. Each of the eighteen beamlines may be independently closed by means of mechanical shutters . The iron and concrete shutters are 2 m thick in the beam direction and a helium atmosphere is provided in the neutron collimator section. The shutters are moved vertically by mechanical jacks to open and close each channel. When closed, the dose rate in the beam at the instrument is < 10 µSv/hr.

COLLIMATION

All ISIS collimation is based on the iris principle proposed by Fluharty. Close to the source in the shutter, the irises are made of scintered B_4C. In the rest of the system, low hydrogen density B_4C rings 5 cm thick are used to define the thermal and epithermal beam. These rings are separated by spacers of slightly greater diameter whose surfaces are either 'bright' (ie can see the source) or 'viewed' (ie can be seen by the detector), but never both. An example is shown in Figure 2. These beam-defining irises are set in a general collimator made of iron shot loaded borated resin, designed to minimise the escape of high energy neutrons and to decouple the beam from its surroundings. Both these components are moulded into rings which are located within a vacuum pipe. Collimator sections are then made up by housing the round vacuum pipes in a 30 cm cross-section rectangular steel box which is filled with iron shot loaded borated wax. This achieves the transition from the round vacuum pipe to a square shape thus facilitating the tight packing of beamline shielding.

NEUTRON BEAMLINE SHIELD AND BEAMSTOPS

Biological shielding of the neutron beamlines is achieved by surrounding the collimation system with steel which is then further enclosed in borated wax. In the absence of sophisticated transport calculations, the following model was adopted to estimate the shielding required transverse to the ISIS beamlines and around the beamstops.

The shielding requirements parallel and perpendicular to the neutron beam are considered separately. In the former case, shielding is dominated by the need to attenuate any very high energy (> 15 MeV) neutrons in the beam. At these energies all materials are quite transparent with very long mean free paths, eg 17 cm in iron. This problem is not important in the beam line shield, since any neutron emerging at a small angle must penetrate a large thickness of shielding material, but it is significant in the design of the beamstops (see below). The spectrum of neutrons emerging transverse to the beam is much softer, and may be described by an evaporation spectrum with a 1/E slowing down component. Here broad beam mean free paths, determined from one dimensional transport calculations, are substantially shorter (eg 6.25 cm in iron, 9.6 cm for borated wax).

At any given distance along the neutron beam, an equivalent point-source term may be generated by considering the number of neutrons which could be stopped in a given spectral region.

$$S_o = \frac{fI_oA}{L^2} \quad n/s$$

where f is the integral dE/E over the spectral range of interest

$I_o = 7\ 10^{12}$ n/eV.sr.200μA.s

A = area of beam

L = distance from source.

This point source will produce a dose D at a distance R of

$$D = \frac{S_o}{4\pi R^2 Q}$$

where Q is the quality factor converting n/cm^2.s to μSv/hr.

The number of mean free paths λ of shielding material required to reduce this dose to D_o at a distance R is then

$$\lambda = \ln\,[D/D_o]$$

The 'standard' beamstop design assumed the following parameters:

f = integral over <u>all</u> energies = 18

$I_o = 7\ 10^{12}$ $\qquad Q = 2$

$A = 20$ cm $\qquad D_o = 2.5\ \mu Sv/h$

$L = 10$ m $\qquad R = 1$ m

giving

$$\lambda = \ln\left[\frac{fI_oA}{L^2}\cdot\frac{1}{QD_o}\cdot\frac{1}{4\pi R^2}\right]$$

$$= 9.9 + \ln\left[\frac{A}{L^2R^2}\right] \qquad \text{with A in cm}^2 \text{ and L, R in m.}$$

To stop the entire beam, the above parameters indicate that 8.3 mfp of shielding material is required to produce the appropriate reduction in dose. Since typical broad beam mean free paths are 6.25 cm for iron and 9.6 cm for CH_2, this suggests 52 cm thickness of iron. Complete absorption of the thermal neutrons leaking from the iron may then be achieved by a further 30 cm outer layer of boarated wax. This system would therefore be suitable to reduce the dose to acceptable levels 1 m from the source. This calculation may be iterated to give the number of mfp required to produce the appropriate dose reduction at the surface of the shield.

Less conservative parameters would be

f = integral from 0.1 - 10 MeV = 5

$I_o = 7\ 10^{12}$ $\qquad Q = 2$

$A = 15\ cm^2$ $\qquad D_o = 2.5\ \mu Sv/h$

$L = 15$ m $\qquad R = 0.85$ m

giving

$$\lambda = \ln\left[\frac{fI_oA}{L^2}\cdot\frac{1}{QD_o}\cdot\frac{1}{4\pi R^2}\right]$$

$$= 8.63 + \ln\left[\frac{A}{L^2R^2}\right]$$

$$= 6.25$$

ie 39 cm of iron.

Although this calculation could be refined and tailored more closely to individual beam parameters, the effective reduction is small. The practical situation at RAL was that a great deal of spare iron shielding was available, but with minimum thicknesses of 60 cm. The practical arrangement for transverse shielding around a beamline is illustrated in Figure 3.

This approach may also be used to give a crude estimate of transverse beamline shielding by regarding the collimation system as a linear beamstop. In the above calculation the beam area A is replaced by the amount of beam scraped off in the section of interest. Because of the logarithmic dependence on A and the need to shield closer to the source, the thicknesses required are similar.

With beamstops, in addition to concern about the transverse shielding, care must be taken to attenuate any high energy component (> 15 MeV) of the neutron beam. In this region mean free paths in all materials increase by a factor 3 (eg $\lambda^{he}{}_{Fe} = 17$ cm). Calculations with the HET Monte Carlo code using the computed ISIS beam escape spectrum indicate that a significant quantity of longitudinal shield is required. Hence a 1 m length of Fe , decoupled with high density polyethylene, is used as a core for ISIS beamstops. (Longitudinal shielding of a beamline is not a problem). This core is then surrounded by the standard 60 cm of iron and 30 cm of borated wax, see Figure 3. Backscattering into the spectrometer is suppressed by a plug of B_4C powder before the beamestop core. All indications are that we have erred on the side of safety*

[*Note Added in proof: New measurements on a partially constructed beamstop at 30 μA show significant radiation levels (50 μSv/hr) on the Fe surface before the addition of the outer wax shield.]

SPECTROMETER SHIELDING

The function of both the bulk shield and the beamline shield and beamstops is to minimise the biological radiation dose in the experimental hall. The spectrometers themselves have additional shielding whose function is to minimise neutron background in the detectors. In general, all spectrometers are enclosed in steel tanks containing a 30 cm thick layer of borated wax (3 atomic % boron) which neutronically decouples the spectrometers from their environment. The interior surfaces of most spectrometers are lined with 5 mm B_4C tiles (< 5 % hydrogen) to minimise the effects of spurious scattering and (n,γ) reactions. The low-hydrogen B_4C mixture is also employed behind all ^{3}He detectors to minimise back-reflected neutrons.

CONCLUSION

The combination of the above shielding concepts and the pulsed nature of the source has produced background levels in the detector systems during ISIS operation which are close to the intrinsic detector limits (eg 0.1 counts/gas tube/minute). No biological radiation problems have been encountered.

ACKNOWLEDGEMENTS

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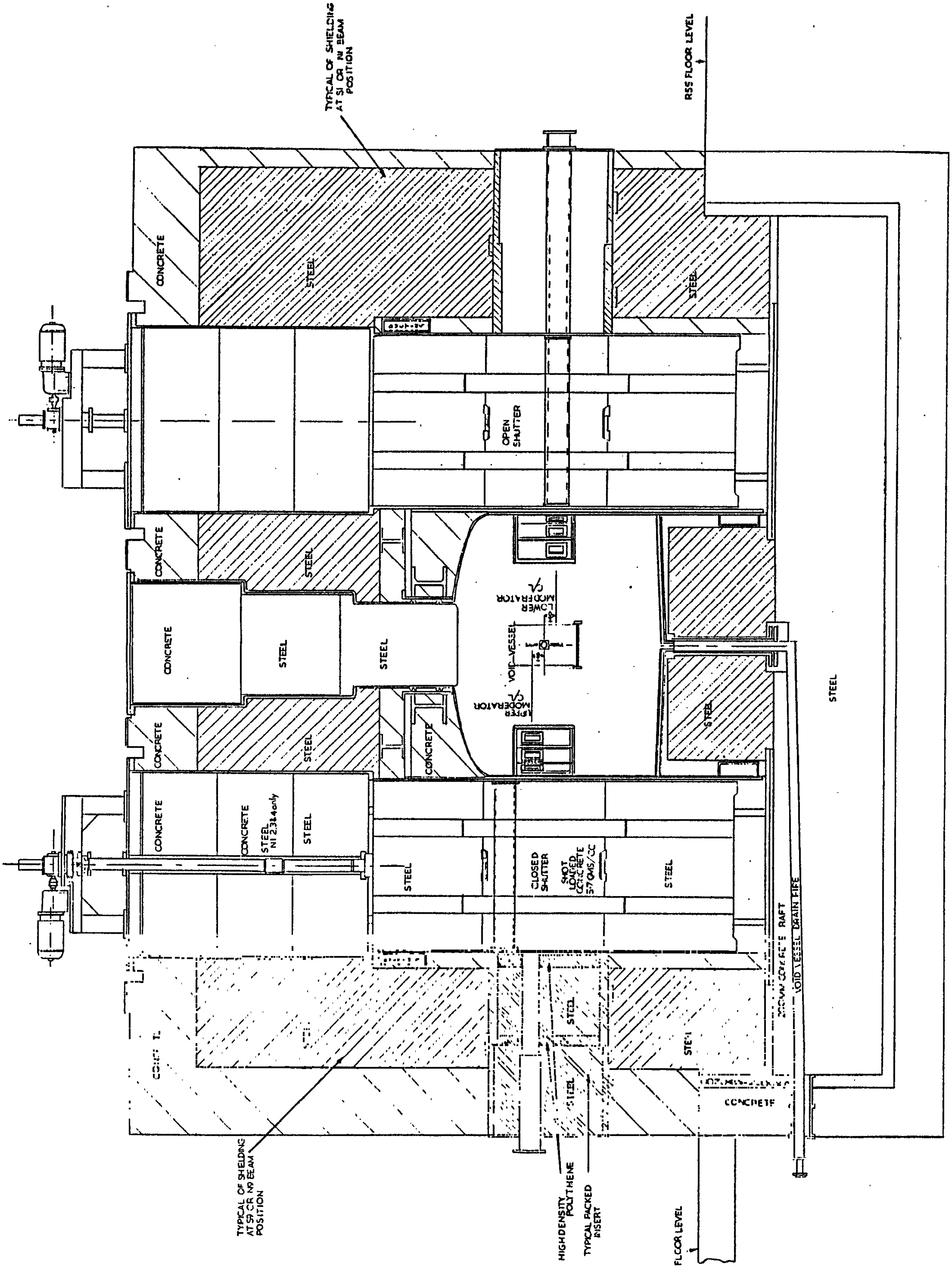

Figure 1a A vertical section through the ISIS bulk shield.

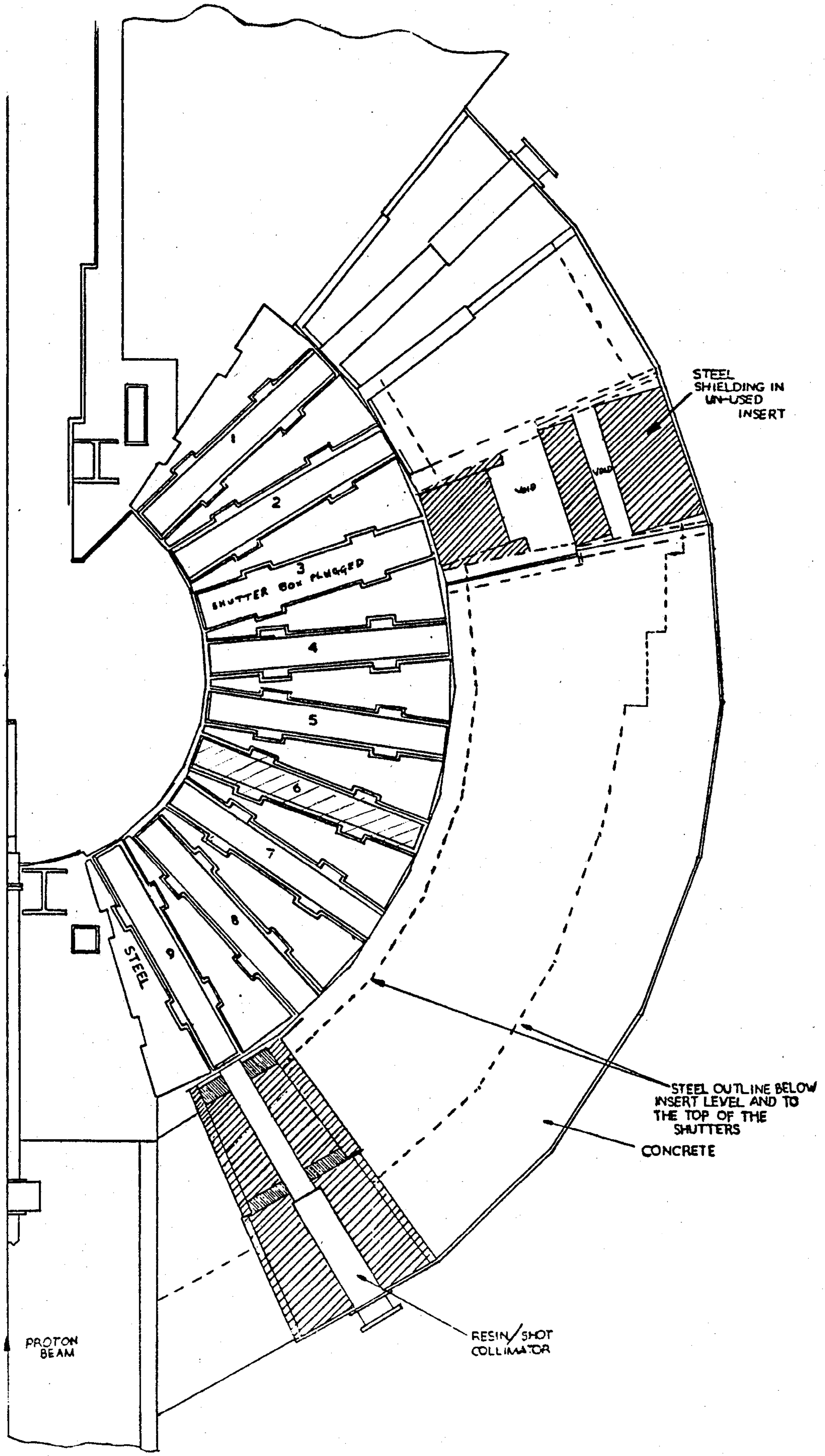

Figure 1b A horizontal section showing the location of nine beam ports in half of the ISIS bulk shield.

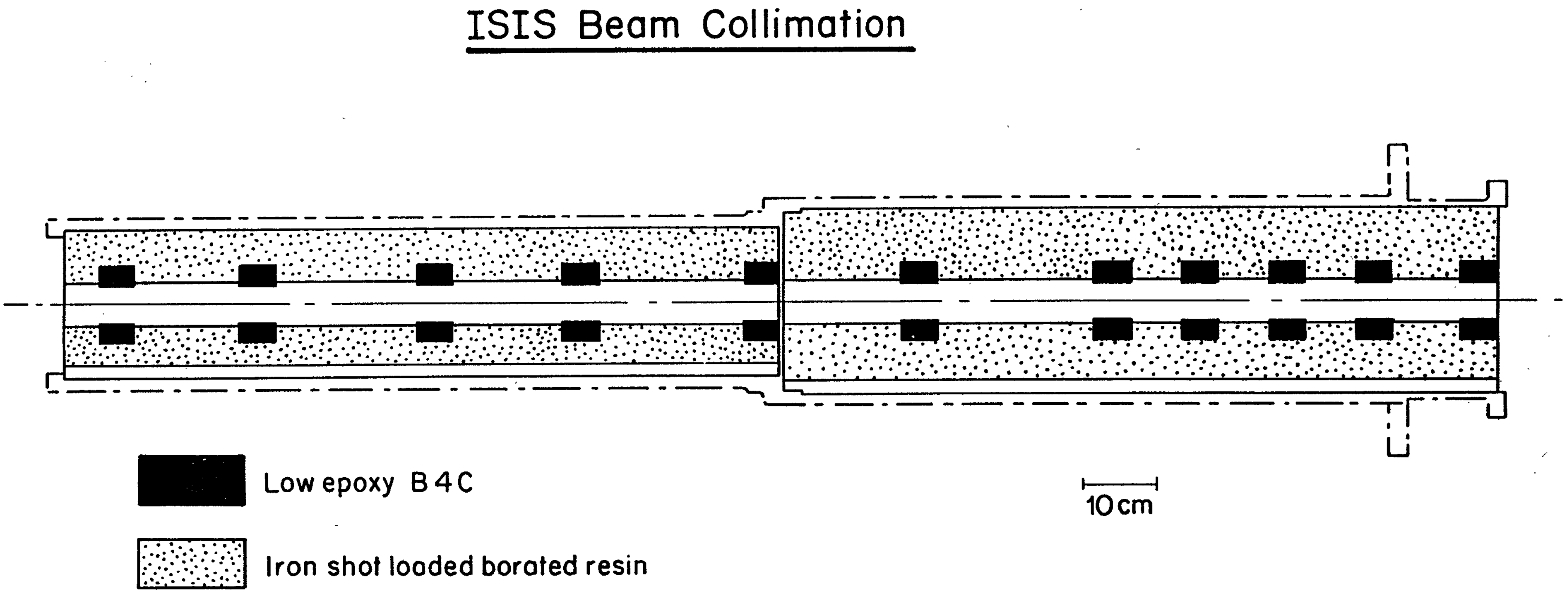

Figure 2 A typical section of ISIS neutron beam collimator showing B_4C beam-defining irises and iron-loaded borated resin spacers.

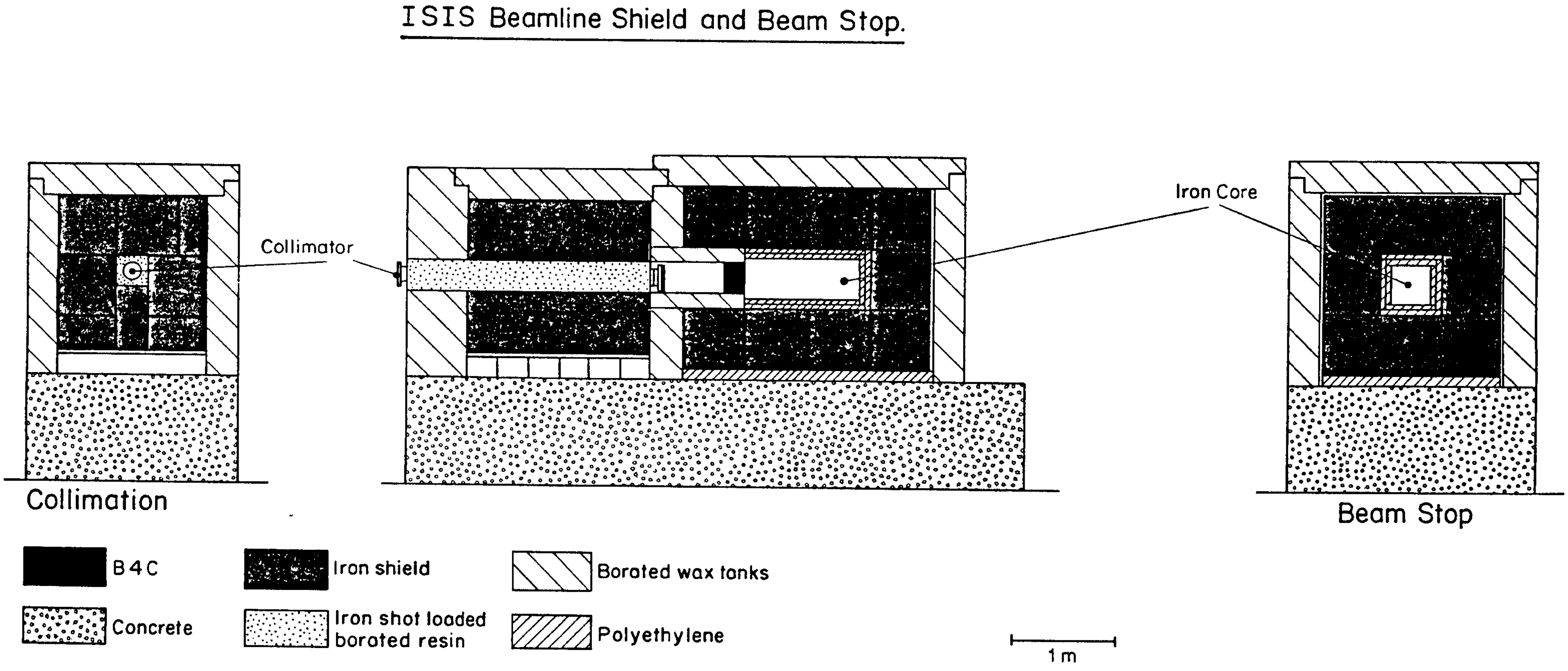

Figure 3 Beamline and beamstop shielding at ISIS.